Charge/Discharge Control of Battery Energy Storage System for Peak Shaving

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Abstract:

A project that involves the installation of a Battery Energy Storage Systems (BESS) at a local electric utility substation is underway. The substation feeds a set of new housing developments, some of which include high energy-efficient homes that are equipped with roof-mounted photovoltaic systems and "smart" grid functions. The purpose of the BESS is to further shave the peak power demand of the substation. This paper describes the load characteristics, selection of size and type of BESS, and different control methods to discharge the energy storage system. The performance of two basic discharge methods is evaluated through simulations using actual hourly load data during the summer of 2008.

Introduction:

The capacity factor of a typical electrical power system in the US is considered low due to the fact that much of the capacity is used only a fraction of the time to meet peak demand. The traditional method to improve capacity factor is to curtail power demand during peak periods by employing Demand Side Management (DSM) strategies, such as Direct Load Control (DLC). This enables the utility to offer customers a discount in exchange for control of large electric loads such as air conditioners and electric water heaters. In the near future, implementation of the "smart grid" is expected to allow further improvement in the capacity factor by shifting the demand curve through either incentives or controls. However, public resistance to the degree of load shifting and high real-time prices entailed in the deployment of demand response programs will likely take place after some point.

Energy storage is another option to augment DSM implementation. By using energy storage systems, a lower cost source of electricity can be effectively provided to meet the peak demand. An energy storage device can be charged during off-peak periods with lower cost sources such as nuclear or coal fired units. This stored energy is then used during peak periods so that high fuel cost units, such as combustion turbines, do not have to serve the load. A virtue of energy storage technology is that it can accomplish the same supply/demand balancing without imposing behavioral constraints on consumers, but at a higher cost.

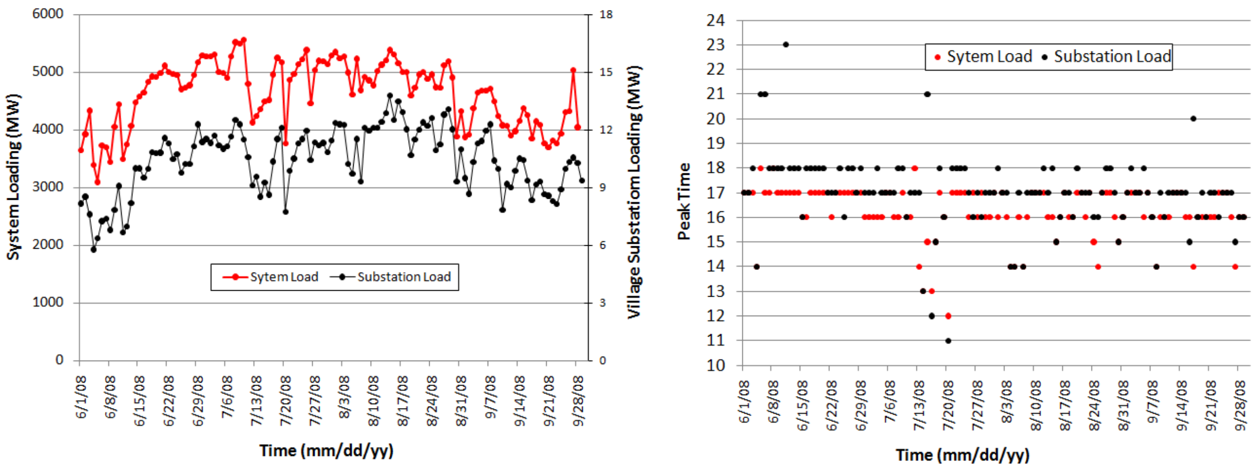
Among energy storage technologies, the Battery Energy Storage Systems (BESS) is becoming attractive due the emergence of new power electronics and improved battery technology. The BESS offers several advantages, including ease of installation in urban areas, short installation period, no emissions, quiet operation, and being modular [1]-[3]. The BESS can also be designed for a variety of other reasons besides peak shaving, namely: 'spinning' power reserve, load frequency control, emergency backup generation, and voltage regulation through reactive power control [4]-[5].

This paper is associated with a project involving the installation of a BESS, for the purpose of reducing peak power demand at a substation that feeds a new housing development that is underway in Las Vegas, NV. In particular, one of the distribution feeders supplied by this substation will be serving a subdivision with highly energy-efficient homes with roof-integrated photovoltaic systems, thus allowing a significantly higher peak load reduction when compared to conventional loads. This paper evaluates the level of peak shaving that can be achieved by the BESS being selected. First, the characteristics of the load at the substation to be housing the BESS are examined during the summer period using last year's hourly data. This is followed by the selection of the battery energy storage system type and size to be used. Then, a list of possible BESS discharge control methods is presented. Finally, two simple discharge controls in terms of time and temperature are simulated using the 2008 substation loading. The paper ends with a conclusion and future work.

Load Characteristics:

The substation that will soon be housing the BESS serves a new housing/light commercial development at the outskirt of the Las Vegas Valley. Many of the energy-efficient homes mentioned above are currently under construction. The substation itself is relatively new and is lightly loaded. The daily substation peak load during the summer months of 2008 is shown in Figure 1(a) below, along with the corresponding system daily peak load. The maximum substation peak power was just below 14 MW during the summer of 2008, while the system peak was 5,550 MW. Note the substation and system peak loads follow the same pattern, i.e., they largely follow similar trends. The correlation coefficient, which indicates the strength of a linear relationship between these two variables, is calculated to be nearly 85%.

Figure 1(b) shows the daily peaking hours of both the substation and system loads. The one important notice that can be made is that the peak of both loads occurred at the same hour less than 50% of the time, more specifically, 47/122 days. Furthermore, the substation peak load occurred one hour after the system peak load nearly half of the time (53/122 days). In addition, there were few days where the peak of both loads occurred outside the 13:00-19:00 time window. This window is considered as the period of peak demand by numerous electric utility companies.

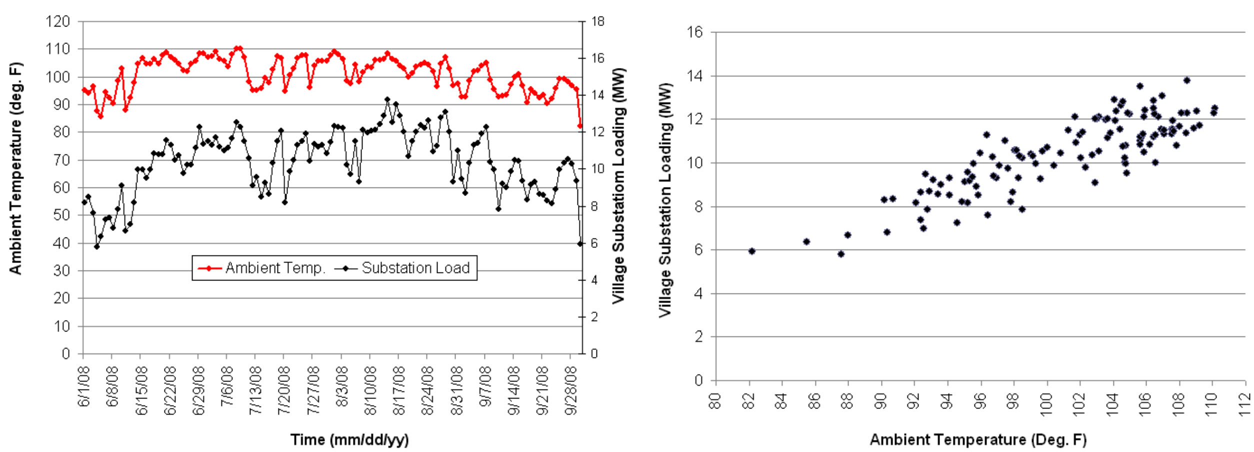


(a) Daily System and Substation Peak Load.

(b) System and Substation Peak Time.

Figure1. System and Substation Loading (Summer, 2008).

The ambient air temperature in the desert southwest can exceed 50°C during the summer months. As a consequence, the air conditioning load causes high peak demand during this period. Figure 2(a) below shows the daily peaks of the ambient temperature and substation load between June 1st and September 30th, 2008. Note also that both quantities follow the same general pattern. Figure 2(b) shows the same variables when plotted against one another. As expected, there is strong correlation between peak demand and temperature. Hence, temperature is a good measure for predicting peak demand. In this particular case, the substation peak is expected to increase by an average value of 0.3 MW every time the temperature increases by 1°F.



(a) Daily Substation Peak and Max. Temperature.

(b) Substation Peak Load vs. Temperature.

Figure 2. Substation Loading and Ambient Temperature (Summer, 2008).

BESS Technology and Sizing:

In the past, lead-acid batteries were utilized for peak power shaving. But the life cycle characteristics were not ideal for the daily cycling capabilities. Today, the two main classes of batteries that are designed for long charge/discharge durations (up to eight hours per day) are flow batteries and high temperature batteries [1]. Industry experts testify that, unlike lead-acid batteries, these devices can cycle on a daily basis and have useful operating lives in the range of 10 to 20 years. Of these two battery technologies, the high temperature battery (e.g., Sodium-Sulfur) has a higher energy density [6]-[7]. Besides energy density and life cycle, cost, efficiency, maintenance requirements, and environmental concerns are among other additional factors that need to be taken into account when selecting a BESS.

Determining the size of a BESS in terms of its power and capacity ratings depends on budgetary constraints, desired level of peak shaving, and the economic benefits [8]-[10]. In this particular project, it was decided that the power and capacity ratings of the BESS should be 1 MW and 6 MWH, respectively. Furthermore, given the limited footprint available at the substation, the most favorable candidate for this application is the NaS battery technology.

BESS Charge/Discharge Methods:

In terms of scheduling, the BESS is operated in the discharging mode to share the burden of the utility during the peak-load time period. In the medium-load period, the BESS is operated in the floating mode. Finally, during the off-peak load period, the BESS is operated in the charging mode to charge the battery bank. The profile duration of the discharge mode depends on the operating regime selected and is based on a pre-programmed discharge profile, which should be designed to maximize the BESS benefits.

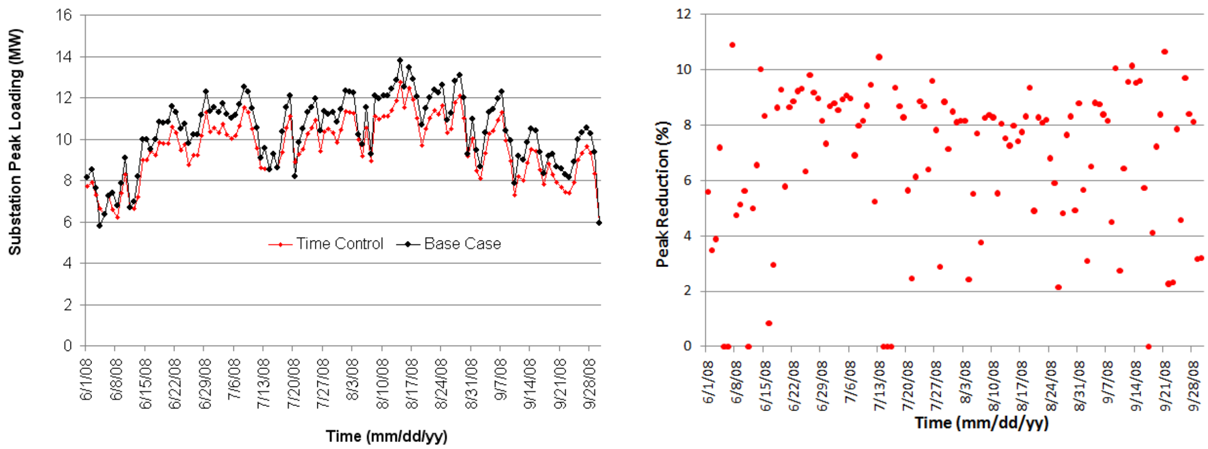
Possible ways to discharge the BESS include the following:

- *Time Control with Fixed Discharge Rate:* e.g., discharge at a rate of 1 MW between 1:00pm-7:00pm.
- *Time-Temperature Control with Fixed Discharge Rate:* e.g., discharge at a rate of 1 MW between 1:00pm-7:00pm *only* if the ambient temperature exceeds 100^{o}F.
- *Time- Temperature Control with Variable Discharge Rate:* e.g., discharge at a rate of 0.1 MW/^{o}F for each degree above 100^{o}F between 1:00pm-7:00pm.
- *Power or Load Control:* e.g., discharge by following the load in excess of 10 MW (until rated power is reached) between 1:00pm-7:00pm.
- *Radio Control (part of SCADA system)*: e.g., discharge according to economic dispatch/unit commitment.

The first two control methods above are illustrated through simulations based on the following assumptions: (i) the BESS is rated such that it is able to deliver a net AC output power of 1 MW continuously for 6 hours; (ii) the net AC-to-AC round trip efficiency, including the losses in the power conversion system and power consumption of the Balance-Of-System (BOS), is 75%; charging the BESS takes place during the low demand period between 12:00 am and 12:00 pm.

Time Control with Fixed Discharge Rate:

When utilizing the hourly load data of the substation under study, we achieve a new daily peak load as shown in Figure 3(a). The daily peak load reduction relative to the base case varies between 0% and 10.8% with an average of 6.7% over the 4-month period, as shown in Figure 3(b). Note that the 0% reduction occurred during the days where the substation peak load took place outside the 1:00pm - 7:00pm window as seen in Figure 2(b); namely, in early June, mid July, and mid September. With a round-trip efficiency of 75%, the total energy loss over the summer added to 183 MWH. This basic method of BESS discharge control is not acceptable as it allows the BESS to cycle even during occasional cool summer days where the peak load tends to occur outside the 1:00pm-7:00pm time window, thus resulting in unnecessary losses and reduced life cycle.

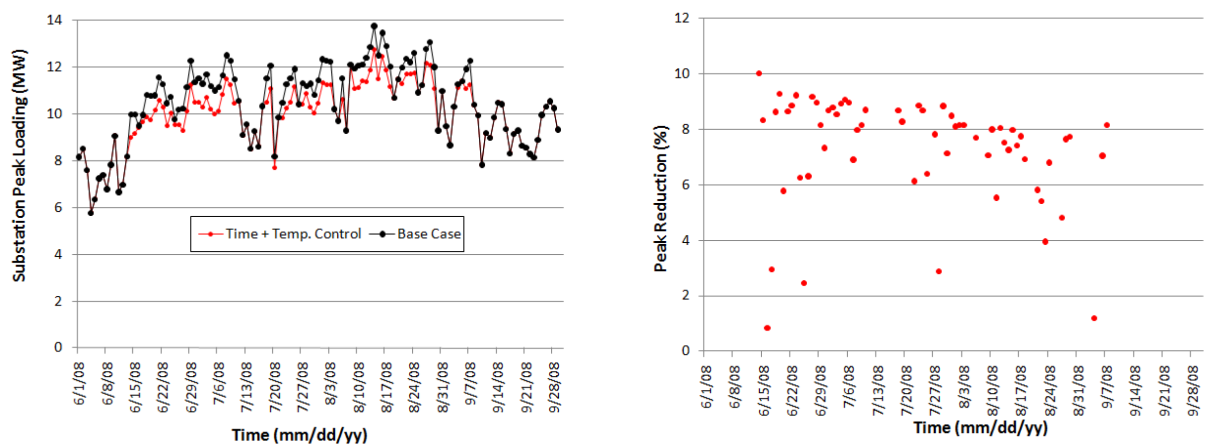


(a) Daily Substation Peak with and w/o BESS. (b) Daily Peak Load Reduction with BESS.

Figure 3: Substation Peak Load Reduction using Simple Time Control.

Time and Temperature Control:

The next simple method to discharge the BESS is to involve the ambient temperature in the decision process. As noted earlier, the daily peaks of the substation load demand and ambient temperature are highly correlated. To avoid the unnecessary BESS cycling during the occasional relatively cool days noted above, one can add a condition to initiate discharging only when the temperature exceeds a certain value. Figure 4(a) shows the resulting daily maximum peak loads if the temperature threshold value is set to 100^{o}F, and Figure 4(b) displays the corresponding daily peak load reduction. In here, the BESS cycled only 61 out of the 122 days, the resulting peak load reduction averages 7.3%, and the energy loss is reduced to 91 MWH.



(a) Daily Substation Peak with and w/o BESS. (b) Daily Peak Load Reduction with BESS..

Figure 4: Substation Peak Load Reduction using Time-Temperature Control.

To illustrate the daily variations in peak load reduction, Figure 5 displays the hourly substation load data with and without the BESS, and the ambient temperature for 3 consecutive days: June 14-16, 2008. Note that the load curve is rather jagged and the peak loads of these particular days are about the same (10 MW, 10 MW, 9.5MW), and occurred all at the same time (6:00 pm). However, the peak load reduction on the third day is very low when compared to those achieved on the first 2 days. The Figure clearly shows that this is due to that fact that the load dropped at a very low rate during the first two hours after peaking when compared to the previous days, thus leading to an unsymmetrical curve with respect to the peak time.

While large swings occur in daily peak load reduction at the substation level, these swing fade away at the system level as illustrated in Figure 6. This is due to the fact that the system load is highly diversified, thus leading to a load curve is far less jagged with a descent level of local symmetry with respect to its peak point. The Figure shows that the average system peak power reduction is around two-hundredth of a percent (nearly equal to the ratio of the BESS power rating and system peak power). Finally, Figure 7 shows the impact of the BESS placement on the top portion of the substation load duration curve (duration of load in excess of 10 MW). Higher peak load shaving can be achieved through demand side management.

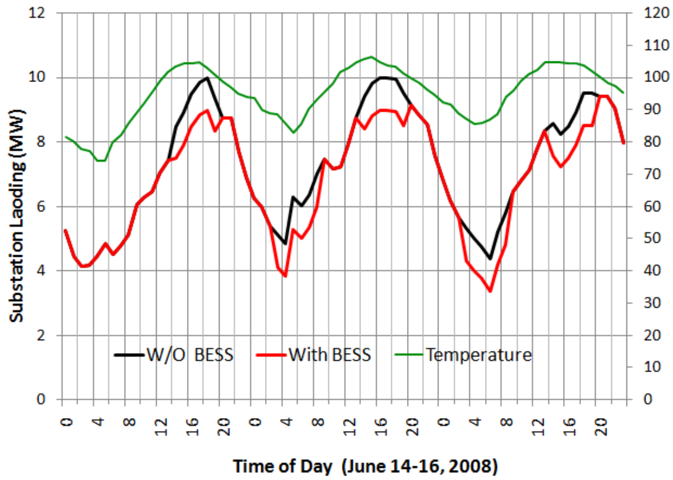


Figure 5: Sample of Hourly Temperature and Substation Load with and w/o BESS.

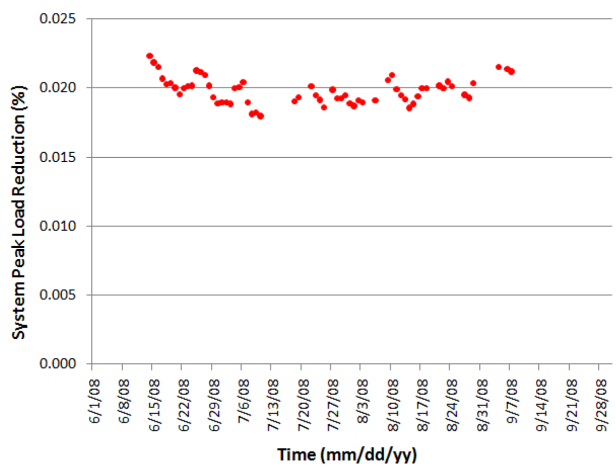


Figure 6: System Peak Load Reduction using Time-Temperature Control.

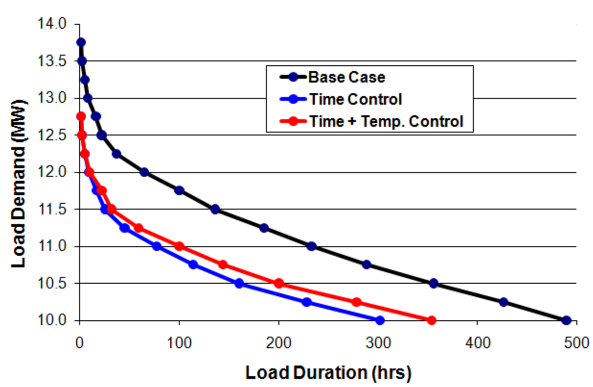


Figure 7: Substation Load Duration Curve with and w/o BESS.

Conclusion and Future Work:

This paper presented part of a local electric utility project whose goal is to shave the peak demand of a substation through a combination of a battery energy storage system, energy-efficient residential homes with roof-integrated photovoltaic systems, and demand side management. The level of peak load reduction by 1 MW/6 MWH battery storage system was simulated using the 2008 hourly load data. Two simple discharge methods using time and ambient temperature as the control signals were illustrated. Future work includes (a) more simulations of the impact of photovoltaic systems and demand side management on further reduction of the peak load, (b) purchase, installation and commissioning of the BESS, (c) implementation of peak shaving control strategies and field performance evaluation.

References:

1. “Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid”, *Electricity Advisory Committee Report*, December 2008.
2. Kyung-Hee Jung; Hoyong Kim; Daeseok Rho; “Determination of the installation site and optimal capacity of the battery energy storage system for load leveling”, *IEEE Transaction on Energy Conversion*, Volume 11, Issue 1, March 1996 Page(s):162 – 167.
3. Miller, N.W.; Zrebiec, R.S.; Delmerico, R.W.; Hunt, G.; Achenbach, H.A.; “A VRLA battery energy storage system for Metlakatla, Alaska”, *Eleventh Annual Battery Conference on Applications and Advances,* 9-12 Jan. 1996 Page(s):241 – 248.
4. Lin, C.E.; Shiao, Y.S.; Huang, C.-L.; Sung, P.S.; “A real and reactive power control approach for battery energy storage system”, *IEEE Transactions on Power Systems,* Volume 7, Issue 3, Aug. 1992 Page(s):1132 – 1140.
5. Papic, I.; “Simulation model for discharging a lead-acid battery energy storage system for load leveling”, *IEEE Transaction on Energy Conversion*, Volume 21, Issue 2, June 2006 Page(s):608 – 615.
6. Iba, K.; Ideta, R.; Suzuki, K.; “Analysis and Operational Records of NAS Battery”, *Proceedings of the 41st International Universities Power Engineering Conference, 2006. UPEC '06*, Volume 2, 6-8 Sept. 2006, Page(s):491 – 495. Bradford P. Roberts, “Sodium-Sulfur (NaS) Batteries for Utility Energy Storage Applications”, *IEEE PES General meeting*, 2008.
7. Bradford P. Roberts, “Sodium-Sulfur (NaS) Batteries for Utility Energy Storage Applications”, *IEEE PES General meeting*, 2008.
8. Oudalov, A.; Chartouni, D.; Ohler, C.; Linhofer, G.; “Value Analysis of Battery Energy Storage Applications in Power Systems” *2006 IEEE PES Power Systems Conference and Exposition, PSCE '06,* Oct. 29 2006 - Nov. 1 2006, Page(s):2206 – 2211.
9. Oudalov, A.; Cherkaoui, R.; Beguin, A.; “Sizing and Optimal Operation of Battery Energy Storage System for Peak Shaving Application”, *2007 IEEE Power Tech*, Lausanne, 1-5 July 2007 Page(s):621 – 625.
10. Alt, J.T.; Anderson, M.D.; Jungst, R.G.; “Assessment of utility side cost savings from battery energy storage” *IEEE Transactions on Power Systems*, Volume 12, Issue 3, Aug. 1997 Page(s):1112 – 1120.